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(54) Title of the invention: Catadioptric optical system

(57) Abstract

Purpose: To provide a catadioptric optical system which requires moderate accuracy for assembling mirrors due to small aberration caused by eccentricity of the mirrors, and accordingly can obtain stable resolution of quarter micron units.

Configuration: A catadioptric optical system is provided in which a first imaging optical system A is formed with an outward path optical system A_1 through which light flux only outwardly penetrates from a first surface R, and an outward-inward optical system A_2 including a concave mirror M_c and lens groups through which both incident light to the concave mirror M_c and reflective light penetrate, an intermediate image of the first surface R is formed by the first imaging optical system A, a first mirror M_1 arranged in the vicinity of the intermediate image so as to lead the light flux from the first imaging optical system A to a second imaging optical system B, re-imaging of the intermediate image is formed on a second surface W by the second imaging optical system B, and a second mirror M_2 and an aperture stop S are arranged in the second imaging optical system B. The catadioptric optical system is characterized in that the second mirror M_2 and the aperture stop S are arranged so as to meet predetermined conditions.

Scope of Patent Claims

Claim 1

A catadioptric optical system in which a first imaging optical system is formed with an outward path optical system through which light flux from a first surface

penetrate only an outward path, and an outward-inward optical system including a concave mirror and lens groups through which both of incident light to the concave mirror and reflective light penetrate, an intermediate image of the first surface is formed by the first imaging optical system, a first mirror is arranged in the vicinity of the intermediate image so as to lead the light flux from the first imaging optical system to a second imaging optical system, re-imaging of the intermediate image is formed on a second surface by the second imaging optical system, and a second mirror and an aperture stop are arranged in the second imaging optical system; characterized in that it has the second mirror and the aperture stop arranged therein so as to meet at least one equation of the following Equation (1) and Equation (2).

$$L_1/L < 0.1 \qquad (1)$$

$$L_1/L_2 < 0.2 \qquad (2)$$

wherein, L_1: a distance on an optical axis from the second mirror to the aperture stop;

L is: a distance on an optical axis measured along an optical path from the first surface to the second surface; and

L_2 is: a distance on an optical axis measured along an optical path from the first mirror to the second surface.

Claim 2

A catadioptric optical system described in Claim 1; characterized in that it meets the following condition.

$$|L_1/f_1| < 1.5 \qquad (3)$$

wherein, f_1 is: a synthetic focal length of a lens group arranged closer to the second surface than to the second mirror in the second imaging optical system.

Claim 3

A catadioptric optical system described in Claim 1 or Claim 2; characterized in that it meets the following condition.

$$|\beta_1| < 0.2 \qquad (4)$$

wherein, β_1 is: an imaging magnification of a lens group arranged closer to the second surface than to the second mirror in the second imaging optical system when the second mirror is an object point.

Detailed Description of the Invention

[0001]

Technical Field to which the Invention Belongs

The present invention relates to an optical system in a projection exposure apparatus used for manufacturing semiconductor devices or liquid crystal display devices and the like with a photolithographic processing. The invention specifically relates to a catadioptric optical system which has resolution of quarter micron units in

the ultraviolet wavelength region by using a reflective system as an element of the optical system.

[0002]

Problems to Be Solved by the Invention

Catadioptric optical systems have been disclosed (Japanese Unexamined Patent Application Publication No. H4-234722 and U.S. Pat. No. 4,779,966) which have been developed to correct field curvature for a projection exposure apparatus used in photolithography processing for manufacturing a semiconductor device or the like. In the catadioptric optical systems, a configuration has been proposed where an intermediate image of a first surface is formed by a first imaging optical system including a concave mirror, a mirror is arranged in the vicinity of the intermediate image so as to lead light flux from the first imaging optical system to a second imaging optical system, and re-imaging of the intermediate image is formed on a second surface by the second imaging optical system. However, in the configuration, since only one mirror is used to bend the optical path, there are problems in that a reticle arranged in the first surface and a wafer arranged in the second surface are not parallel to each other, and synchronous scanning of the reticle and the wafer is difficult. For that reason, another catadioptric optical systems has been proposed with a configuration where a second mirror is arranged in the second imaging optical system so that the reticle and the wafer are parallel to each other.

[0003]

Nonetheless, when a mirror is used in a catadioptric optical system in general, there is a concern that a large aberration may occur by eccentricity tilt of the mirror. For that reason, in order to attain an image with stable resolution of quarter micron units, remarkably high accuracy is required in tolerance of the mirror assembly. Taking the point into consideration, the present invention aims to provide a catadioptric optical system which requires moderate accuracy for assembling mirrors due to small aberrations caused by eccentricity of the mirrors, and accordingly can obtain stable resolution of quarter micron units.

[0004]

Means to Solve Problems

In order to solve the problem, in the catadioptric optical system according to the present invention a first imaging optical system is formed with an outward path optical system through which light flux from a first surface penetrate only an outward path, and an outward-inward optical system including a concave mirror and lens groups through which both of incident light to the concave mirror and reflective light penetrate, an intermediate image of the first surface is formed by the first imaging optical system, a first mirror is arranged in the vicinity of the intermediate image so as to lead the light flux from the first imaging optical system to a second imaging optical

system, re-imaging of the intermediate image is formed on a second surface by the second imaging optical system, and a second mirror and an aperture stop are arranged in the second imaging optical system, when

L_1 is: a distance on an optical axis from the second mirror to the aperture stop;

L is: a distance on an optical axis measured along an optical path from the first surface to the second surface; and

L_2 is: a distance on an optical axis measured along an optical path from the first mirror to the second surface,

the catadioptric optical system is characterized in that the second mirror and the aperture stop are arranged therein so as to meet at least one equation of the following Equation (1) and Equation (2).

$L_1/L < 0.1$ (1)

$L_1/L_2 < 0.2$ (2)

[0005]

With the above configuration, the second mirror is arranged close to the aperture stop of the second imaging optical system, and therefore, all light beams passing through the second mirror are relatively nearly parallel with the optical axis, and thus, eccentricity aberrations (coma aberrations, astigmatism aberrations, and lens distortion aberrations) caused by eccentricity tilt of the second mirror reduces. Therefore, the tolerance of the eccentricity required for the second mirror becomes moderate. The Equations (1) and (2) shown above indicate the extent of the closeness between the second mirror and the aperture stop, and thus, when any one of the Equations (1) and (2) is not satisfied, the eccentricity aberration caused by the eccentricity tilt of the second mirror easily becomes large, and accordingly, the tolerance of the eccentricity required for the second mirror becomes remarkably strict.

[0006]

In the present invention, when

f_1 is: the synthetic focal length of the lens group arranged closer to the second surface side than to the second mirror in the second imaging optical system, it is preferable that the following condition is satisfied;

$|L_1/f_1| < 1.5$ (3).

Since f_1 becomes large to some extent in proportion to L_1 by satisfying the conditional Equation (3), the aberration amount of the second imaging optical system decreases. On the contrary, when the conditional Equation is not satisfied, f_1 becomes small, and accordingly, correction of aberration in the second imaging optical system becomes difficult.

[0007]

Furthermore, in the present invention, when

β_1 is: imaging magnification of the lens group arranged closer to the second surface side than to the second mirror in the second imaging optical system when the second mirror is the object point, it is preferable that the following condition is satisfied;

$|\beta_1| < 0.2$ (4)

The conditional Equation (4) is a condition for reducing the inclination between each light beam at the position of the second mirror. If the conditional Equation is not satisfied, each light beam is inclined to each other at the position of the second mirror by being largely shifted from the parallel state to each other, and accordingly, uneven reflectance occurring in the second mirror between the light beams becomes significant.

[0008]

Embodiments of the Invention

Embodiments of the present invention will be described with reference to the drawings. Fig. 1 and Fig. 3 each show catadioptric optical systems according to a first and a second embodiment of the present invention. The optical system of both embodiments are configured such that the present invention is applied to a projection optical system where a circuit pattern on a reticle R is reduced and transferred onto a semiconductor wafer W. The projection optical system includes a first imaging optical system A where an intermediate image of a pattern drawn in the reticle R is formed, a first mirror M_1 arranged in the vicinity of the intermediate image, and a second imaging optical system B where re-imaging of the intermediate image is formed on the wafer W. The first imaging optical system A includes an outward path optical system A_1 through which light flux from the reticle R penetrates only for an outward path, and an outward-inward optical system A_2 through which light flux from the outward path optical system A_1 penetrates outward and inward. The outward-inward optical system A_2 is provided with a concave mirror M_c so as to reflect the light flux from the outward path optical system A_1, such that a lens closest to the concave mirror M_c is a concave lens. Light flux penetrating the inward path of the outward-inward optical system A_2 is led to the second imaging optical system B by the first mirror M_1. An aperture stop S is arranged in the second imaging optical system B, and a second mirror M_2 is arranged in the front side of the aperture stop S. The exposure range of the catadioptric optical system forms a slit shape or a circular arc shape without including the optical axis, and the catadioptric optical system is configured to obtain a wide exposure range by performing synchronous scanning for the reticle R and the wafer W.

[0009]

Tables 1 and 2 given below show specifications of optical members in the first and second embodiments. In the Tables, the first column lists numbers of each optical

surface from the reticle R, the second column labeled "r" lists curvature radii corresponding to each optical surface, the third column labeled "d" lists intervals between each optical surface, the fourth column lists each lens material, and the fifth column lists the group numbers of each optical member. In the fifth column, a "*" mark indicates a inward path. In addition, a refractive index n for the standard of used wavelength (193 nm) of a synthetic quarts (SiO_2) and fluorite (CaF_2) are as follows.

SiO_2: n=1.56019

CaF_2: n=1.50138

Furthermore, Table 3 below contains values of L_1, L, L_2, and f_1, and values of parameters in each of the conditional Equations mentioned above for both embodiments. In addition, Fig. 2 and Fig. 4 show lateral aberrations of the first and second embodiments. In the lateral aberration drawings, Y indicates an image height.

[0010]

Table 1

	r	d		
0	–	49.998	reticle R	
1	369.115	18.000	SiO_2	A_1
2	245.893	0.500		
3	227.674	33.705	CaF_2	A_1
4	-373.082	18.803		
5	-324.258	20.532	SiO_2	A_1
6	332.817	1.674		
7	340.581	20.389	SiO_2	A_1
8	604.750	27.395		
9	∞	35.000	SiO_2	A_1
10	∞	16.943		
11	391.176	30.000	CaF_2	A_2
12	-982.727	6.592		
13	-417.793	20.000	SiO_2	A_2
14	-1216.731	261.353		
15	478.547	40.000	CaF_2	A_2
16	-908.632	11.323		
17	325.213	20.000	SiO_2	A_2
18	208.331	48.917		
19	-196.257	20.000	SiO_2	A_2
20	1370.871	0.500		
21	430.209	42.793	CaF_2	A_2
22	-366.694	61.625		
23	247.465	25.000	SiO_2	A_2
24	286.274	68.753		
25	508.228	40.000	SiO_2	A_2
26	-930.828	27.931		
27	-313.824	25.000	SiO_2	A_2
28	-1017.267	19.454		
29	-276.064	25.000	SiO_2	A_2
30	1335.454	32.821		

31	-360.416	32.821	concave mirror M_c A_2
32	1335.454	25.000	SiO_2 A_2*
33	-276.064	19.454	
34	-1017.267	25.000	SiO_2 A_2*
35	-313.824	27.931	
36	-930.828	40.000	SiO_2 A_2*
37	508.228	68.753	
38	286.274	25.000	SiO_2 A_2*
39	247.465	61.625	
40	-366.694	42.793	CaF_2 A_2*
41	430.209	0.500	
42	1370.871	20.000	SiO_2 A_2*
43	-196.257	48.917	
44	208.331	20.000	SiO_2 A_2*
45	325.213	11.323	
46	-908.632	40.000	CaF_2 A_2*
47	478.547	261.353	
48	-1216.731	20.000	SiO_2 A_2*
49	-417.793	6.592	
50	-982.727	30.000	CaF_2 A_2*
51	391.176	1.943	
52	∞	236.637	first mirror M_1
53	471.443	36.090	CaF_2 B
54	-1089.261	3.979	
55	306.858	20.000	SiO_2 B
56	247.195	312.806	
57	812.165	25.000	SiO_2 B
58	2628.418	145.000	
59	∞	145.508	second mirror M_2
60	-1094.809	30.000	SiO_2 B
61	1598.936	30.114	
62	–	81.437	aperture stop S
63	-266.544	45.218	CaF_2 B
64	2115.935	0.550	
65	-213.134	30.096	SiO_2 B
66	-642.205	15.142	
67	1328.716	30.000	SiO_2 B
68	-654.044	1.236	
69	-210.004	45.167	SiO_2 B
70	-304.557	19.703	
71	-166.497	45.000	SiO_2 B
72	-72.336	6.218	
73	-71.786	66.262	SiO_2 B
74	2042.086	17.000	
75	–		wafer W

[0011]

Table 2

	r	d	
0	–	60.000	reticle R

1	-210.000	18.000	SiO_2 A_1
2	-233.058	1.734	
3	301.818	32.109	CaF_2 A_1
4	-415.393	19.449	
5	154862.242	15.248	SiO_2 A_1
6	-528.109	5.460	
7	-316.309	18.000	SiO_2 A_1
8	275.570	74.064	
9	342.313	48.000	CaF_2 A_2
10	-248.024	1.806	
11	-250.000	20.000	SiO_2 A_2
12	3438.110	286.849	
13	390.013	40.000	CaF_2 A_2
14	-2017.162	22.849	
15	421.041	20.000	SiO_2 A_2
16	230.317	47.916	
17	-222.542	20.000	SiO_2 A_2
18	988.626	7.270	
19	11949.023	27.617	CaF_2 A_2
20	-328.913	0.500	
21	365.306	42.285	SiO_2 A_2
22	-1713.365	160.144	
23	-283.704	30.000	SiO_2 A_2
24	1076.349	30.701	
25	-353.136	30.701	concave mirror M_c A_2
26	1076.349	30.000	SiO_2 A_2*
27	-283.704	160.144	
28	-1713.365	42.285	SiO_2 A_2*
29	365.306	0.500	
30	-382.913	27.617	CaF_2 A_2*
31	-11949.023	7.270	
32	988.626	20.000	SiO_2 A_2*
33	-222.542	47.916	
34	230.317	20.000	SiO_2 A_2*
35	421.041	22.849	
36	-2017.162	40.000	CaF_2 A_2*
37	390.013	286.849	
38	3438.110	20.000	SiO_2 A_2*
39	-250.000	1.806	
40	-248.024	48.000	CaF_2 A_2*
41	342.313	4.064	
42	∞	180.000	first mirror M_1
43	506.214	34.041	CaF_2 B
44	-256.332	3.017	
45	-250.000	20.000	SiO_2 B
46	-1453.242	422.966	
47	∞	150.000	second mirror M_2
48	-285.380	30.000	SiO_2 B
49	-954.824	50.000	
50	–	78.332	aperture stop S

51	-220.000	45.000	CaF_2 B
52	-2665.536	6.535	
53	-200.000	27.411	SiO_2 B
54	-516.467	18.844	
55	632.373	30.000	SiO_2 B
56	-1060.585	19.112	
57	-553.788	45.000	SiO_2 B
58	5823.302	0.500	
59	-153.299	45.000	SiO_2 B
60	-120.000	1.243	
61	-125.615	66.000	SiO_2 B
62	3036.218	17.000	
63	–		wafer W

[0012]

Table 3

Embodiment No.	1	2
L_1	205.6	230.0
L	3287.2	3150.0
L_2	1388.2	1290.0
f_1	192.0	207.5
(1) L_1/L	0.06	0.07
(2) L_1/L_2	0.15	0.18
(3) $\|L_1/f_1\|$	1.07	1.11
(4) $\|\beta_1\|$	0.1409	0.1932

[0013]

In the first embodiment as shown above, the second mirror M_2 is placed at a position of 205.6 from the aperture stop S, and in the second embodiment, the second mirror M_2 is placed at a position of 230 from the aperture stop S. As a result, coma aberrations, astigmatism aberrations, and distortion aberrations due to the eccentricity are small, and thus, a catadioptric optical system which is stable in resolution of quarter micron units can be obtained. In addition, uneven reflectance caused by the second mirror M_2 can be reduced. Furthermore, in both of the embodiments, the second mirror M_2 is arranged in the front side of the aperture stop S, but may be arranged in the rear side of the aperture stop S as long as each conditional Equations is in the range of satisfaction.

[0014]

Effects of the Invention

In the catadioptric optical system according to the present invention as described above, since the second mirror is arranged close to the aperture stop in the second imaging optical system, it is possible to make aberration caused by eccentricity small, and reduce uneven reflectance caused by the second mirror.

Brief Description of the Drawings

Fig. 1

Fig. 1 is a structural diagram according to a first embodiment.

Fig. 2

Fig. 2 is a lateral aberration diagram according to the first embodiment.

Fig. 3

Fig. 3 is a structural diagram according to a second embodiment.

Fig. 4

Fig. 4 is a lateral aberration diagram according to the second embodiment.

Description of Symbols

A	first imaging optical system
A_2	outward-inward optical system
M_c	concave mirror
M_2	second mirror
R	reticle
A_1	outward path optical system
B	second imaging optical system
M_1	first mirror
S	aperture stop
W	wafer